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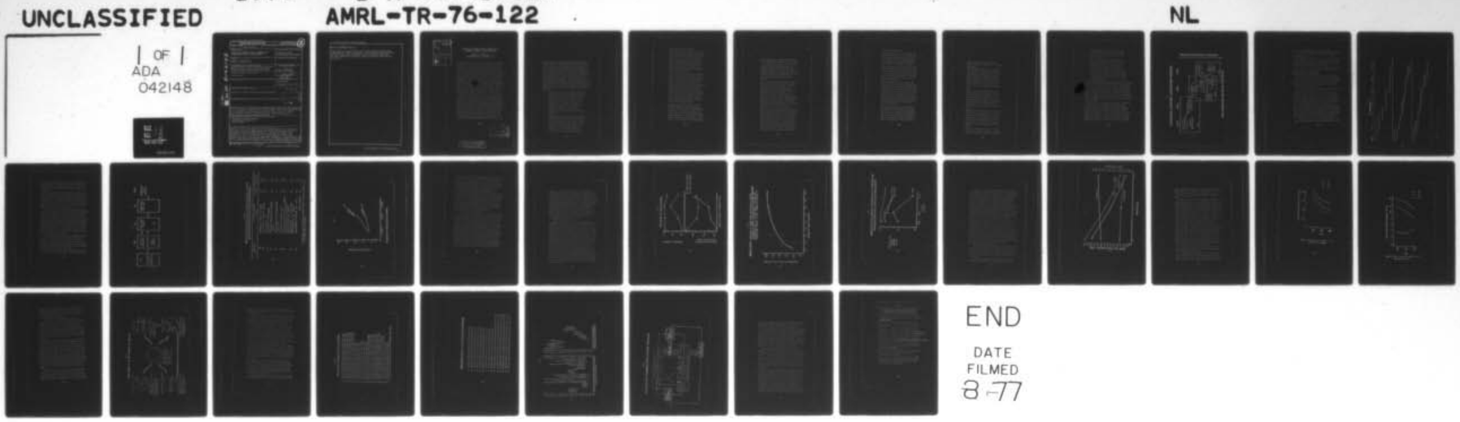

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This paper reviews and summarizes approximately fifteen (15) years of man-machine simulation research in command, control and communication systems conducted by this the Aerospace Medical Research Laboratory. Summaries of decision aiding techniques for tactical command decision making conducted at Ohio State University are made. Descriptions and summary findings of C^3 simulations for the Back Up Interceptor Control System (BUIC III), the Advanced Airborne Warning and Control System (AWACS) and Remotely Piloted Vehicle Systems (RPVs) are presented. (cont on p 1473B)

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Block 20. ABSTRACT (Cont'd) ffr p 1473 A)

A comparison of results obtained with real-time operator-in-the-loop simulations with computer simulations using a Systems Integrated Network of Tasks (SAINT) model predictions were illustrated to demonstrate the power and utility of iterating computer simulation with real-time simulations.

(1473B)

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MAN-MACHINE COMMAND-CONTROL-COMMUNICATION SIMULATION STUDIES IN THE AIR FORCE

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1. Introduction. Unlike many of the Air Force aeronautical weapon systems which have been based on a technology developed in the early 1900's, C^3 systems are comparatively new (since WW II) and have primarily blossomed in direct proportion to computer science technologies. Early human engineering efforts were addressed to aeronautical engineering problems, aircraft control and safety (altimeter studies), where the human operator (pilot) contributed significantly to system performance. Since safety of flight was so preeminent in early engineering endeavors for designing and testing [illegible]t, the man-machine compatibility problems were "roughly en[illegible]" by aeronautical designers based upon their intuitive kno[illegible]ge of human performance. Human engineering, as a discipline, developed, nurtured and thrived on making these "gut engineered" designs more efficient and safe through knowledge and data of man's performance capabilities.

On the other hand, C^3 systems, at least computerized versions, have only a 25-30 year history. Further, with the advent and development of computers to process the information in these systems, the functions performed became uniquely more "intellective", in an analogous sense, to human functions. Data are input to the computers (sensed), stored (memory), processed (problem solving), etc. This evolution of C^3 systems and the sister technology of computer science was prone to a greater propensity to be "gut engineered" or to "bright idea" engineering than even aeronautical systems. Also, operational personnel constantly strove for bigger and faster computers to minimize cycle and processing times without good evidence that the advantages to be

gained in system effectiveness warranted the expenses. The natural assumption is that more rapidly sensed and processed data can be used most effectively by operators and commanders in the field environment without taking into account the human's perceptual, intellective and information processing compatibility with the computer. Therefore, we find new C^3 systems insisting on 2.5 sec. cycle time of radar history without good evidence that this hardward/software capability can be effectively used.

2.0 Man-Computer Information Processing Capabilities. Following is a listing of human information processing capabilities and limitations published in a Honeywell document (12297-FR) entitled, Information Professing Framework for Man/Computer Interaction: A Research Study, which defines current state-of-the-art research issues.

- Man has extensive heuristic information-processing capabilities which cannot be duplicated by machine; he is able to apply creative solutions to unique problems and to eliminate large numbers of alternatives during the solution process (i.e., man is adaptable). The computer can be used to search and retrieve information based on man's direction and guidance. Due to its great speed of calculation, the computer can be an aid even when trial and error may be the only way to proceed.

- Man's problem-solving process appears to contain a random element which enables him to attempt solutions which may not be a direct result of standard rule-following procedures; he is able to innovate and, thus, may arrive at unpredictable but successful, results. The computer could be used as a partner in this "ideation" activity, by recording man's output and providing a medium

for generating novel relationships.

- Man requires a certain minimum amount of time in which to consolidate his thoughts (i.e., perform complex processing); this time is required primarily for the transfer of information between short- and long-term memory stores and for associating the information with the task at hand. A man/computer system organized on the principle of memory-to-memory communication should increase the efficiency of this consolidation and association process.

- Man uses definable strategies in his information-processing activities; these strategies vary in their rationality and effectiveness; man's strategies may reflect some basic cognitive style which is characteristic of an individual's approach to a problem regardless of task specifics; some strategies, however, are modificable by training or performance aids. In a computer-based system where such idiosyncracies form part of the data base, different cognitive styles would not necessarily limit or handicap performance. The less efficient strategies appear to place a greater strain on human memory, and this could be alleviated by computer-aiding.

- Man's performance appears to suffer when he is required to perform several tasks in parallel, especially when the tasks are in different stages of completion. The computer's capability for storage would be an asset in this regard, for the system could actually switch from tasks in various stages of solution as either relevant data were received by the system or human "insight" occurred.

- Man is limited in his sensory and cognitive ability to deal with incoming information, unless the pattern is regular and predictable; man has difficulty in dealing with multiple sensory inputs. This is an example where an interactive system could buffer the information (i.e., hold it in queue) until man could process the information. The system could thus compensate for the tendency of man to deal with information overload by selective attention.

- Man has a finite channel capacity which limits the amount of information in a stimulus configuration that he can deal with effectively; as task stimulus complexity increases, performance is degraded; relevant redundancy can help alleviate this difficulty; however, irrelevant task redundancy has a disproportionate interference factor. Given the appropriate guidelines, many of these types of problems could be eliminated by preprocessing the stimulus inputs. The effects of various levels of this approach on system performance and efficiency are not known at present.

- Man requires fairly complete information on his performance to maintain or increase his effectiveness; his own expectancies can exert a powerful influence when feedback is periodic during critical periods of skill acquisition; man progresses from a requirement for general knowledge of results to a need for specific task feedback. A system dedicated to interactive information processing could be programmed to adjust feedback requirements relative to the level of performance and his location in the task sequence (i.e., incorporate principles of

computer-aided instruction).

- The more deterministic the task environment, the simpler the task situation for man; however, man can effectively deal with complex probabilistic environments better than can a computer alone. The optimum approach to complex, unbounded problems appears to be man/computer synergism.

- Some relationships are more difficult for man to deal with than others (e.g., conjunctive problems versus problems based on disjunctive rules). In theory no such differences should be present when man is interacting with a computer to solve such problems, because the limitations due to human memory could be reduced.

- Most human beings are very susceptible to the influence of set or orientation generated by problem pattern, either structural or temporal; this rigidity can be evoked by relatively few occurrences of particular events; the effect is reduced by forgetting, thus suggesting the locus of the problem is in memory, probably short-term store. The capability of the computer to monitor behavior patterns would be useful in developing rules for alerting the operator (i.e., "breaking set"; another area for study).

- Man appears in many diagnostic situations to be a conservative information processor in that he does not use all of the information available in input data and accordingly tends to acquire more data than he either needs or can use prior to some terminal behavior. Computer aids have been proposed and implemented to reduce this human

propensity by allocating to a machine those tasks in which the man is more likely to display this tendency.

- Man's ability to formulate novel relationships is reflected in the fact that he is an effective information processor despite his cognitive limitations; this related to his ability to develop heuristics for information reduction and conservation. The role of the computer in this regard would be as a vehicle for depicting these relationships and for performing the analysis necessary for evaluation and verification.

- Man has been found to be more responsive to a criterion of accuracy than timeliness when both are system parameters. The computer has the capability to operate in non-real time (i.e., "fast time"), thereby providing the human operator the capability to evaluate many more alternative courses of action within limited time constraints without sacrificing his search for accuracy.

- Humans in decision situations tend to delay their action selection inappropriately; this is especially prevalent when the man is at a relative disadvantage. Again computer-aiding is a reasonable mechanism for channeling the operator's thought processes and overcoming this tendency toward inertia in problem solving and decision making.

- Man has a nearly limitless capacity for variety in his behavior; this is reflected in his unique capacity for innovation, originality, and creati-

vity; man has a special capability in the idea-generation aspect of problem solving. The computer can enhance this process, but it can by no means duplicate it.

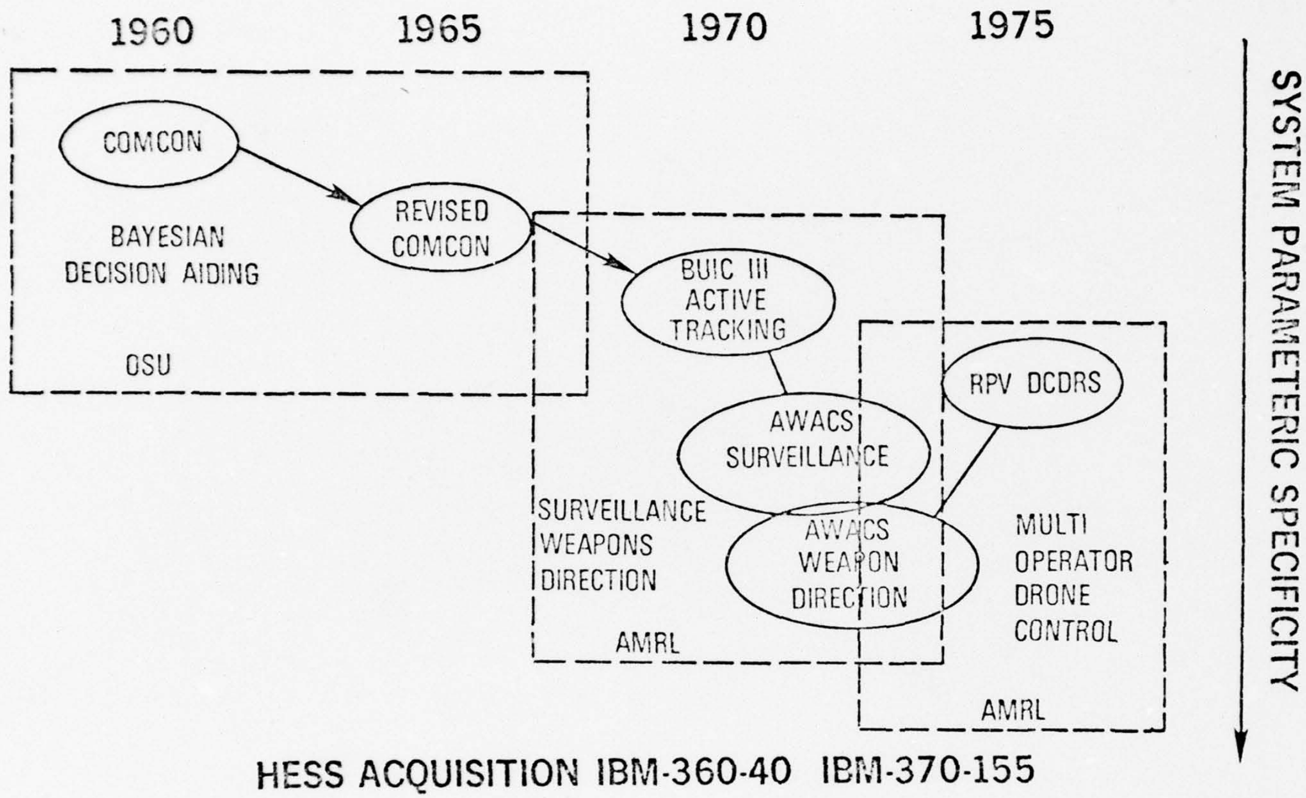
- Man is acknowledged to be a superior pattern recognizer especially when the patterns are both temporal and figural in content. Further, the interpretation of patterns, such as voice communication, relies upon man's ability to contribute his own experiences to the interpretation. Thus, for the present, man's role in this regard cannot be duplicated by machine but can be enhanced by providing variable displays capable of controlling pattern changes

3.0 C^3 MAN-MACHINE SYSTEMS EXPERIMENTS. Fig 1 shows a fifteen year history of Man-Machine Command and Control Simulation starting in the early sixties with a program in Tactical Command and Control decision aiding carried out under contract with Ohio State University's Human Performance Center. This program was dubbed COMCON (a simulated threat diagnosis system) and involved in an early version which had little feedback loops in the system whereas the revised COMCON included an action sequence and feedback load in addition to threat evaluation per se and operated on a greatly reduced time base.

When the OSU program was terminated in 1968, it was decided to develop an in-house capability in the Aerospace Medical Research Laboratory for Man-Machine Command-Control Systems Research. The Human Engineering Systems Simulator (HESS) was acquired involving an IBM 360-40 computer graphics facility. Since in the OSU program we investigated the man-machine diagnostic system behavior with very limiting assumptions of the sensor/surveillance environment, it was decided to direct our systems simulations activities to the surveillance, and to some extent,

FIG 1

COMMAND/CONTROL SIMULATION HISTORY



the weapons direction functions of BUIC III and AWACS.

The most advanced of our multi-operator command-control system is reflected in our Remotely Piloted Vehicle--Drone Control Facility Simulation.

Fig 2 illustrates the developments of our in-house program in terms of the major simulations, the systems independent variables manipulated in the simultations and the major operator and system performance measures taken (dependent variables).

The following sections will attempt to summarize the research problems and some of the more significant findings from these complex system simulation experiments.

Ohio State University COMCON Studies

The program at Ohio State University under the direction of Dr. William C. Howell was designed to assess the use of computers to aid a decision process of the kind that may be found in a command-control system. This program dealt exclusively with diagnostic decision functions within the context of a simulated intelligence threat evaluation system.

Although the overall question was addressed to determining if the computer can be used to assist man made decisions in a realistically complex command-control situation, we were also interested in determining what aspect of the decision function should be automated and how much can be gained by automating these functions. This is tantamount to asking how the computer can assist in the system inference process as opposed to simple predecisional data processing (tabulation, storage, etc.).

The general philosophy used to develop the simulation framework was not to attempt duplicating any existing system however, we did try to simulate basic functional characteristic of a high level diagnostic system (air reconnaissance). By adopting such a philosophy, it should be possible to determine principles which would generalize across a broad spectrum of such systems.

The simulation vehicle consisted of a 1000x1000 mile area called an aggressor territory which was under surveillance. Simu-

FIG 2

C^3 SIMULATION

FY70 FY71 FY72 FY73 FY74 FY75 FY76

BUIC/AWACS SINGLE OPERATOR STUDIES

MULTIOPERATOR AWACS SURVEILL.

WEAPONS DIRECTION

MULTI OPERATOR AWACS SURVEILL.

RPV DRONE CONTROL →

RADAR TRAIL-HISOTRY

RADAR CLUTTER

THREAT LOAD

BLIP/SCAN

PENETRATOR TACTICS

TRACK FAILURE RATE

CREW SIZE

SORKLOAD DISTRIBUTION

NO. OF RPVS

RPV GUIDANCE SYSTEMS

FORCE MIXING

PROB OF TARGET DETECTION

TRACK INITIATION TIME

TRACK MAINTENANCE

"OVERALL GOOD TRACKING"

PERCENT"KILLS"

DISTANCE FROM BRL AT KILL

FUEL USAGE

CROSS TRACK ERROR

GROUND SPEED ERROR

PATCHES AND VELOCITY CHANGES

lated activities included troop movements, vehicular movements, etc., in this area. The input to the system was the processed reconnaissance data about these activities. These reports were then analyzed by the system in order to diagnose pending threat of attack.

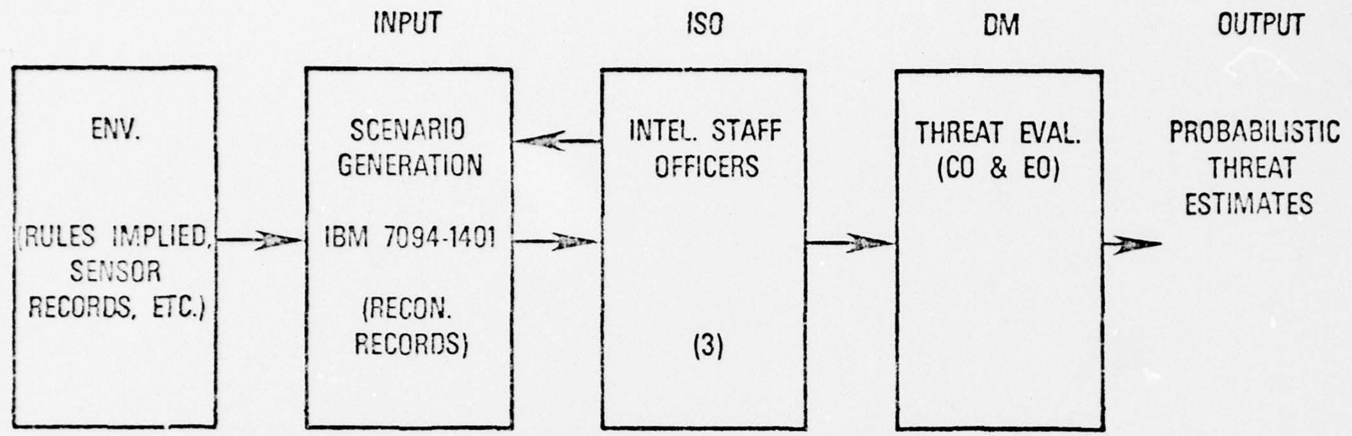
The block diagram of the system is depicted in Figure 3. In general, the three Intelligence Staff Officers (ISO) attempted to determine what was present in the environment based on the reconnaissance data and report this to the Commanding Officer (CO). The CO evaluated these reports to determine what the data meant in terms of the aggressor's plans, e.g., training maneuver?, diversionary action?, etc. The system output was a set of probability estimates that each of these hypotheses was true.

The diagnostic process can be conceived of as actually consisting of two processes: first, is some estimation of the bearing that each bit of diagnostic data has upon the states of possible threat (evaluation process). It has been assumed that man is best suited to perform the evaluation function while the computer should perform the aggregation. By so doing man's special intuitive skills can be used for individual datum evaluation while the machine's capability for rapid calculation and memory can be used best for combining data to yield an overall diagnosis. To accomplish this latter function the machine must be provided a rule for determining how the information should be combined. The rule used in this program was Bayes Theorem.

The overall results of this program are summarized in Table 1. In general an improvement of 13% in correct diagnoses is achieved with automated over complete manual estimation. The greatest advantages of computer-aided solutions seem to occur when there is degraded input data due to low fidelity of sensors or stressful situations due to the information load generated by the amount of data to be processed. (See Fig 4)

One reason that the computer aids the man under these situations is that it considers all of the information no matter how

FIG 3



INPUT
ISO
DM
OUTPUT
ENV.
(RULES IMPLIED, SENSOR RECORDS, ETC.)
SCENARIO GENERATION
IBM 7094-1401
(RECON. RECORDS)
INTEL. STAFF OFFICERS
(3)
THREAT EVAL. (CO & EO)
PROBABILISTIC THREAT ESTIMATES

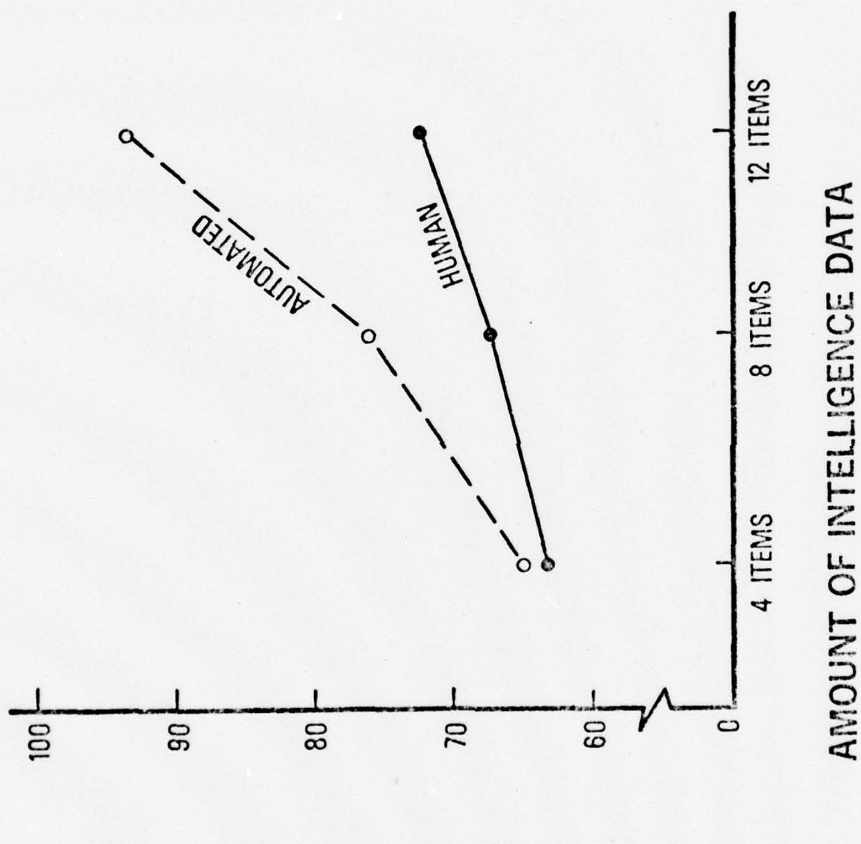
TABLE 1

SUMMARY OF OVERALL COMPARISONS BETWEEN HUMAN AND AUTOMATED AGGREGATION EFFECTIVENESS

EXPERIMENT	RANGE OF CONDITIONS STUDIED	AVERAGE DECISION SCORES* HUMAN	AUTOMATED
12A	EXPERIENCE: 114 HOURS -- 234 HOURS	47	54
12B	FIDELITY (INPUT): COMPLETE - MEDIUM	56	55
	FIDELITY: MEDIUM - LOW	21	31
13	TIME STRESS: 1 -7 MIN./DECISION		
15	AUTOMATED AGGREGATION AID: PRESENT - ABSENT	25	45
14	HUMAN CONTROL OVER AGGREGATION AID: LOW - HIGH	74	74
16	KNOWLEDGE OF RESULTS: 0 - 100%	34	41
18	PAYOFF FUNCTIONS: LINEAR, LOG, ALL - NOTHING INFORMATION LOAD: 4 - 12 DATA ITEMS PRIOR UNCERTAINTY: HIGH - MEDIUM	62	70
19	INFORMATION LOAD: 4 - 12 DATA ITEMS PRIOR UNCERTAINTY: HIGH - MEDIUM	69	80
20	NONINDEPENDENT INPUT DATA: NONE - HIGH	69	74
	OVERALL AVERAGES:	45	58

* IN MOST CASES, THE SCORE REFERS TO PERCENT CORRECT DECISIONS AVERAGED OVER THE ENTIRE RANGE OF CONDITIONS

FIG 4


PERCENT CORRECT DIAGNOSES
100
90
80
70
60
0
AUTOMATED
HUMAN
4 ITEMS
8 ITEMS
12 ITEMS
AMOUNT OF INTELLIGENCE DATA

degraded whereas man tends to ignore all but the highest quality information. Another reason seems to be that man is more conservative than the data actually justify. It appears, however, that subjects can improve in these respects with training in the logic of an aggregation procedure (Bayesian technique). And they seem to do rather well if not under a great deal of stress.

AMRL Surveillance and Weapons Direction Simulation

With the acquisition of the Human Engineering Systems Simulator (HESS) in April of 1969, at that time a computer graphics system (IBM 360-40 with four IBM 2250 graphics scopes) now updated to an IBM 370-155 with 512K byte CPU, the early command/control simulations were addressed to surveillance problems. Since the OSU program emphasized the command decision functions, with a highly abstracted and mathematical representation of the threat environment it was decided to concentrate on the sensor-surveillance end of the system of our in-house program.

• BUIC III Active Tracking Studies

Early simultations focused on the active tracking function for a digitalized radar sensor system. Subject-operators observed a computer display unit simulating radar clutter and radar trails of aircraft of differing penetrating velocities (150K and 500K). Radar information was stored, cycle by cycle, up to a limit of 3, 5, 7 or 9 twenty second cycles and then presented sequentially rapidly enough to give apparent perceptual movement in the track/trails. Subject/operators initiated tracks on the aircraft and controlled computer processing by light pen and keyboard actions. Since only portions of the total BUIC III active tracking function could be simulated on the HESS, other actual tasks were simulated by a stochastic computer model (Siegel and Wolf, 1963). The Siegel-Wolf model is a computer program for generating a sample time for a task by a Monte Carlo method. When task equipment is in the planning stage, being developed or not physically present, the Siegel-Wolf model can generate realistic task times on that

equipment. Fig 5 shows the findings of this simulation. Note that probability to detect was less and average time to initiate tracks was longer for the slower aircraft. It appeared that there was little advantage to have more than seven returns per trail in the track, both in terms of times to initiate and probability of detection. Two significant points seem to derive from this effort; first, using both computer simulation of tasks which could not be physically simulated in sequential combination with physical real-time simulation that significant sensor system effects on operator performance could be demonstrated and secondly, such a simulation approach can provide the trade-off data for deciding how much computer processing/storage is required to optimize operator surveillance detection performance.

•AWACS Surveillance Studies

Early in 1970 the Airborne Warning and Control System (AWACS) System Project Office (SPO) requested that AMRL investigate surveillance operators ability to detect and initiate tracks on targets with varying degrees of ground and sea clutter. A series of simulation studies was initiated to investigate various sensor and radar filtering design issues. Fig 6 shows some early results from these studies on an operator's probability of correct track initiation as a function of the number of tracks he had to maintain throughout a fifty minute mission. It can be seen that under varying clutter density levels and varying target introduction rates into a 75x75 nautical mile surveillance zone that the more targets the operator had to maintain track on, the greater the probability of initiating new targets entering the zone. Also Fig 7 shows some results of these same studies. Probability of correct initiation of penetrator targets is plotted as a function of target introduction rate and clutter density. Note that in the worst case condition, when penetrators are entering the surveillance zone at four per minute and clutter density is fairly high, that one out of ten of enemy attackers will penetrate our surveillance zone undetected.

FIG 5

SUMMARY OF BUIC STUDIES

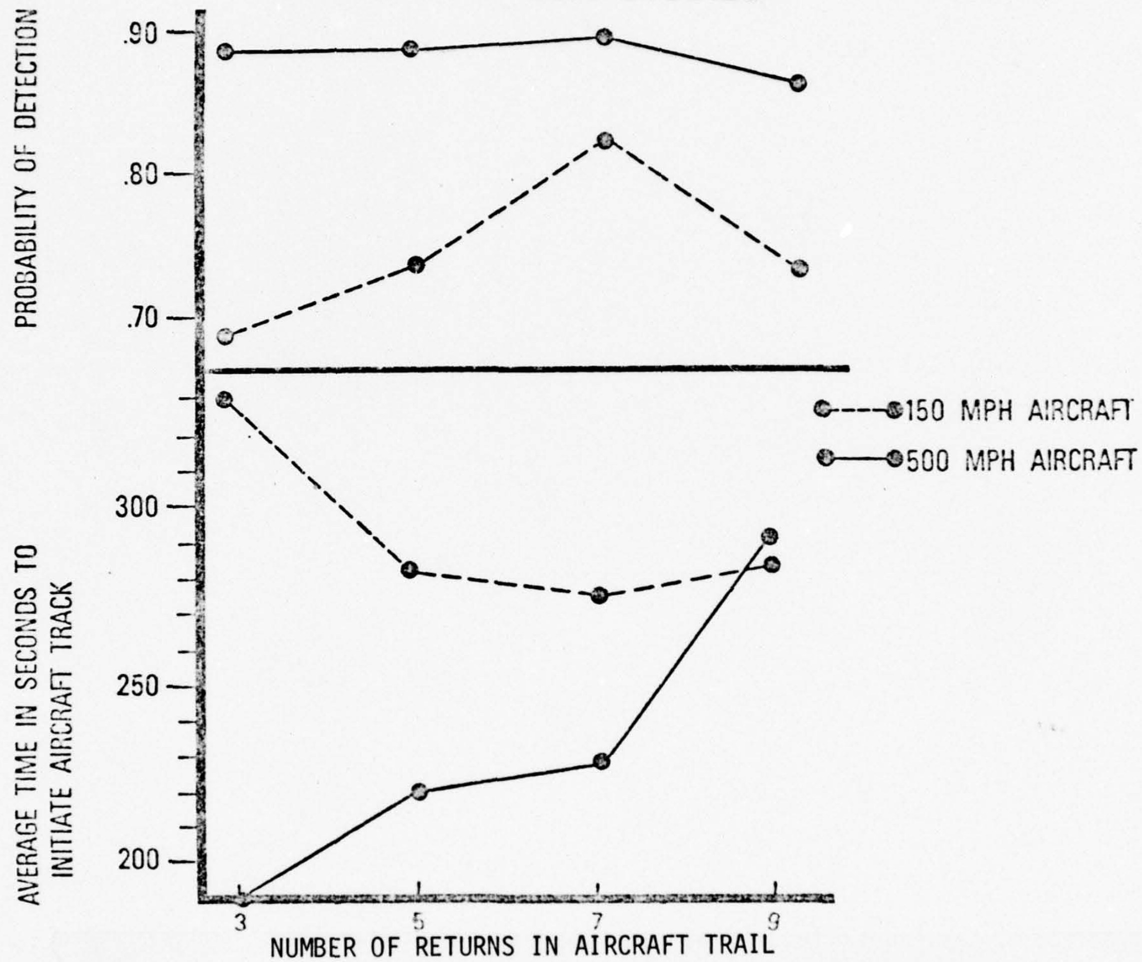


FIG 6

AWACS DATA - PROBABILITY OF CORRECT TRACK INITIATION AS A FUNCTION OF NUMBER OF TRACKS MAINTAINED FOR TWO MISSION CONDITIONS (INTRODUCTION RATE = 4, CLUTTER DENSITY = 0.16 AND 0.32). MISSION TIME COVERED = 50 MIN. NUMBER OF SUBJECTS = 6.

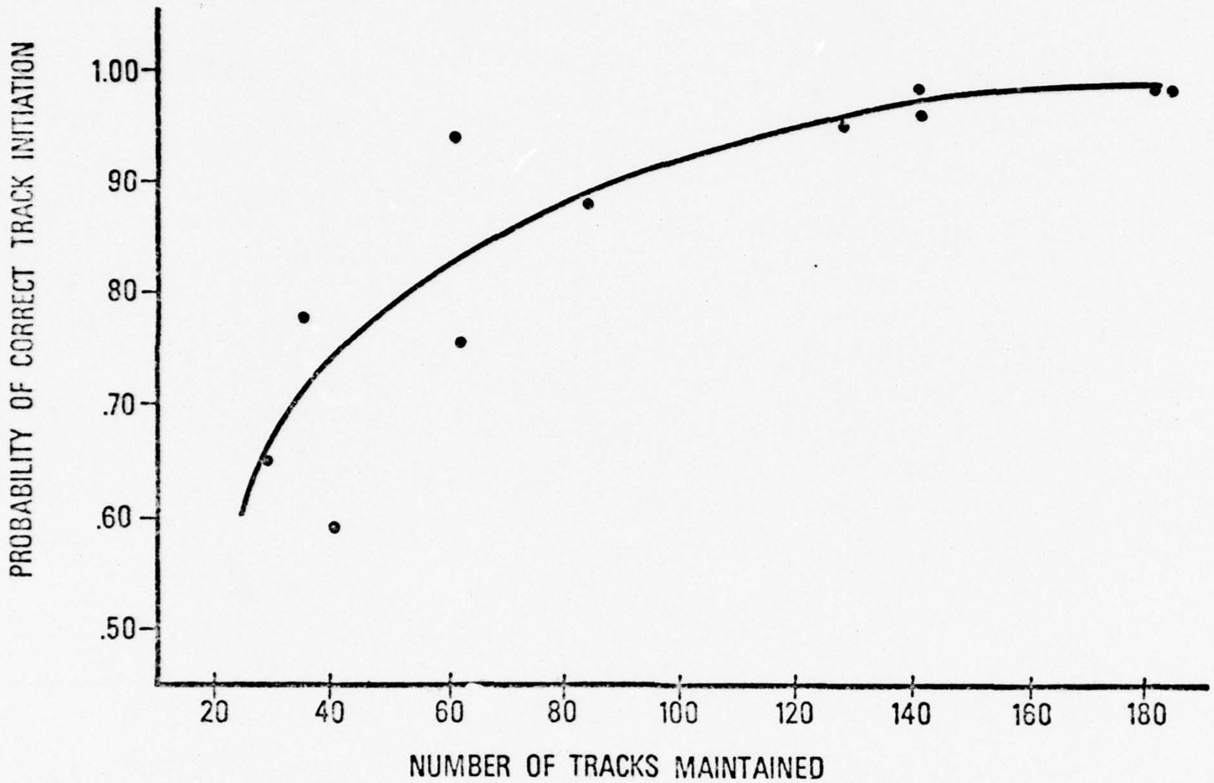
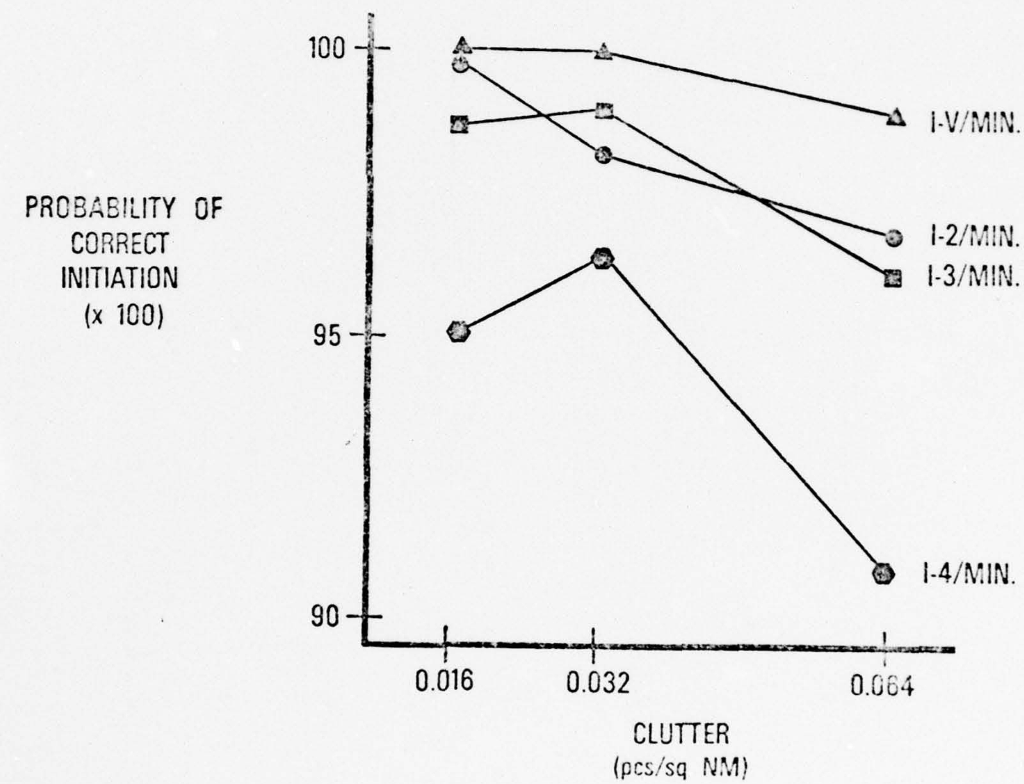


FIG 7

PROBABILITY OF CORRECT INITIATION AS A FUNCTION OF INTRODUCTION RATE (I) AND CLUTTER DENSITY



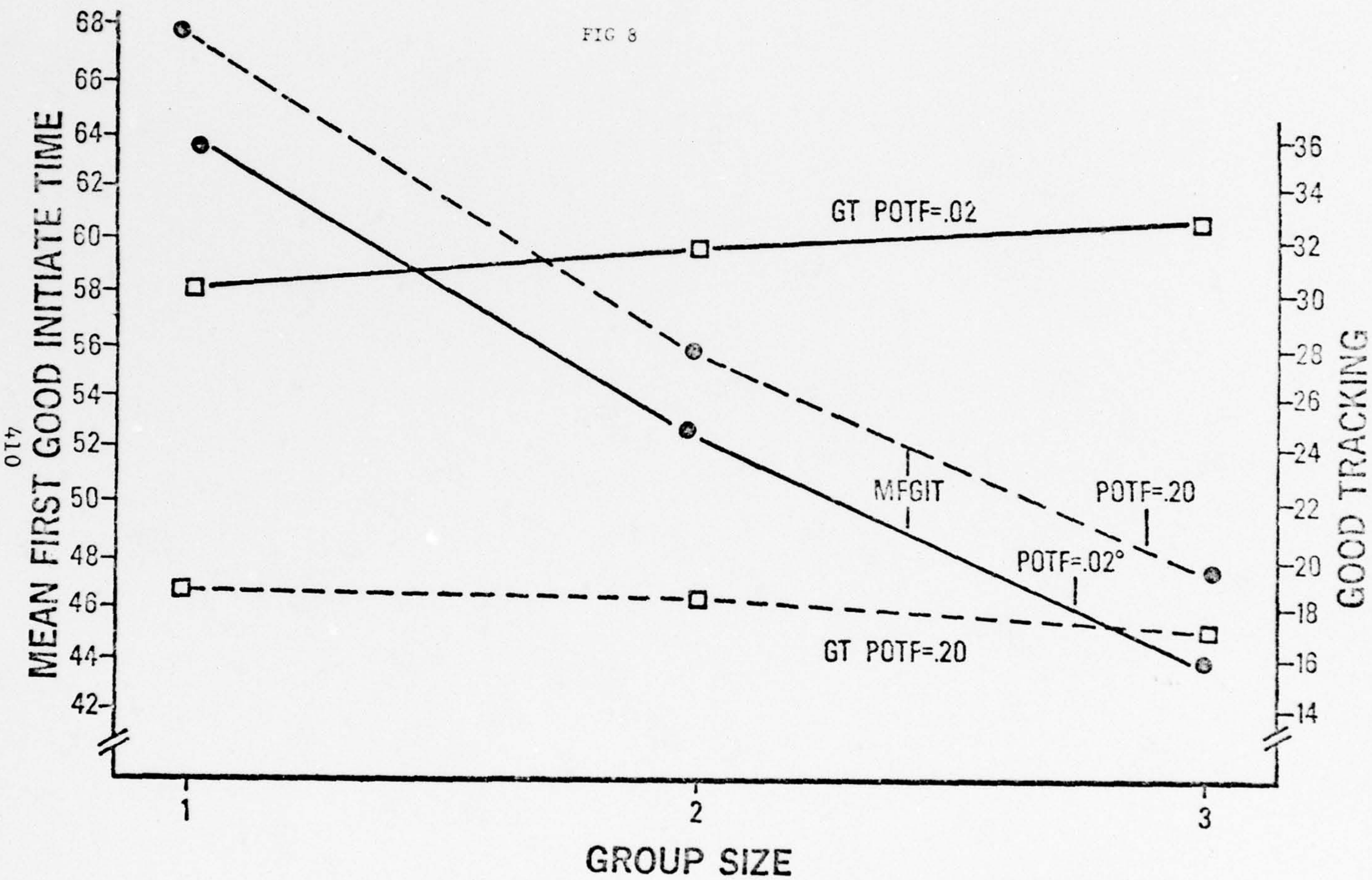
In addition to the questions from the SPO, on the ability of a single operator to detect and initiate targets in high land/sea clutter conditions, we were concerned with the possible advantages in adding additional operators to monitor the same surveillance area. Fig 8 illustrated several points from the multi-operator studies. First, two measures of performance were taken in the simulations--an operator performance measure, mean first good initial time (MFGIT) or the average time it takes the operators to initiate targets and an overall good tracking score (GT), which is a systems measure containing both operator performance and computer tracking performance. Both of these measures were plotted as a function of number of operators 1-3 and a radar system parameter, probability of track failure (POTF). It should be evident that the systems designer and/or commander might reach two entirely different conclusions about whether or not to have multiple operators survey the same area as a function of radar performance (i.e. probabilities of track failure). There is little advantage to adding additional operators if overall good tracking is of primary concern, but a significant advantage if identifying and initiating tracks (operator measure) is of primary concern. Further the expenses involved in improving radar track failure (sensor parameter) only has its effect on overall good tracking. The issue of deciding to use only an operator measure or a system measure must be negotiated between the system designers, R&D managers (SPO) and the operational using command.

•AWACS Weapons Direction Simulation

A natural follow-on to the surveillance study effort was to (1) obtain data on weapons controller performance in a simulated weapons management simulation and (2) compare alternative methods for mediating information inputs to a computer via an associated CRT display of aircraft status information based on digitalized radar returns.

The principle experimental variable investigated was the method of indicating points on the CRT display interface which

FIG 8


MEAN FIRST GOOD INITIATE TIME
68
66
64
62
60
58
56
54
52
50
48
46
44
42
GOOD TRACKING
36
34
32
30
28
26
24
22
20
18
16
14
GT POTF=.02
MFGIT
POTF=.20
POTF=.02°
GT POTF=.20
1
2
3
GROUP SIZE

mediated transferral of data between the operator-controller and computer system. Three methods were investigated: (1) a hand-held pen with fiber optics link to the computer system, (2) a track ball cursor controller, and (3) a force stick cursor controller.

The task used in the simulation required the weapons controllers-operator to direct up to 10 friendly interceptors against attacks by enemy bombers. Five of the fighters were in the air as the simulation began. Each had an airspeed of 500 knots and an altitude of 10,000 feet. The enemy bombers entered from the west side of a 200 x 200 mile area and were distributed randomly along the 200 mile boundary upon entry and traveled in a generally easterly direction toward a bomb release line (BRL) which spanned the display from top to bottom (north to south) at a point 185 miles east of their entry points. Enemy bombers entered with an airpseed of 500 knots and air altitudes of 40,000 feet.

The controller-operator's primary task was to direct the fighters to intercept and "kill" the attacking bombers as far from the BRL as possible. In addition to the experimental variables of light-pen, track-ball and force stick methods of interaction, a second experimental variable of "load" was manipulated. Three levels were investigated. The first load condition was characterized by an attack involving a single wave of 16 bombers. Under the second load condition, 2 waves of 20 bombers attacked with approximately 6 1/2 minutes elapsing between waves. Load three was a single wave of 40 bombers all entering the display area within the first 3 minutes of the session.

The performance measures included: number of kills, average distance from BRL at kill, fighters down for lack of fuel, fuel used and number of operator actions.

Figs 9 and 10 show the comparative effects of the three modes of interacting with the computer generated display as a function of load condition. Note that both in terms of average distance from BRL at "kill" and the fuel used, that the light pen

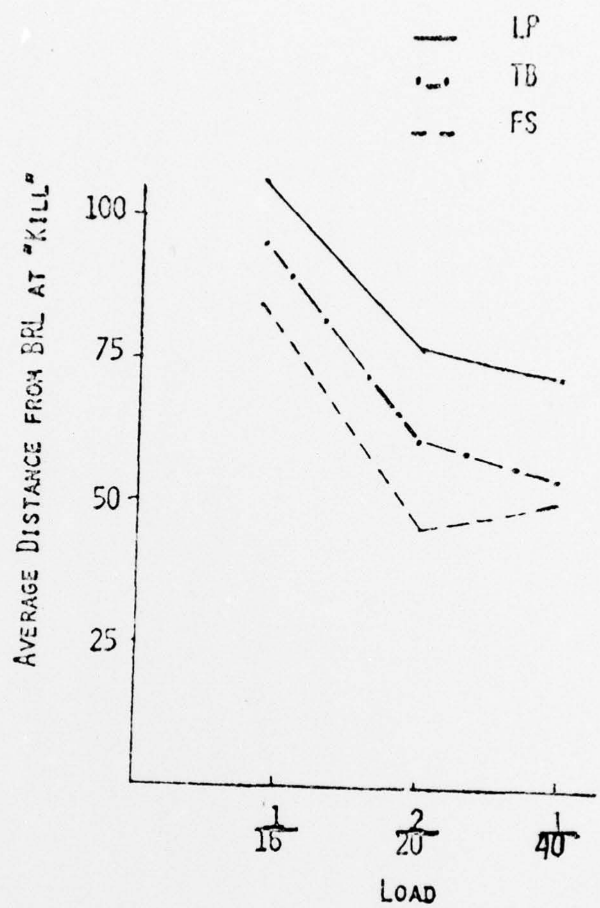


FIGURE 9 AVERAGE DISTANCE FROM BRL AT "KILL" FOR CONTROL MODE AND LOAD.

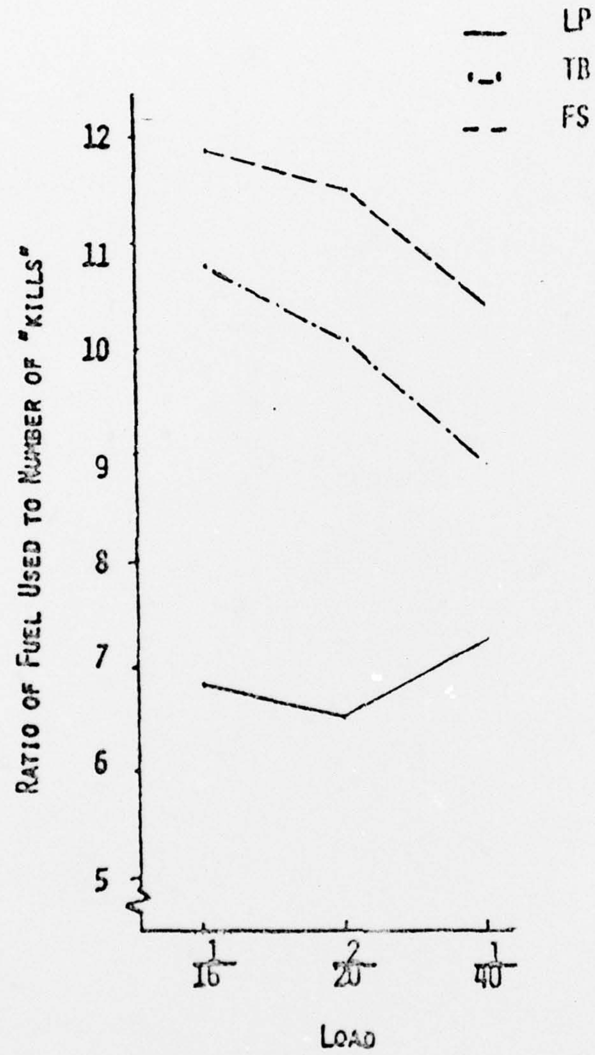


FIGURE 10. Ratio of Fuel Per Aircraft "Killed" by Control Mode and Load.

was superior to track-ball and force stick. It is evident that the random access nature of the light pen is superior for performing a weapons control task. It is also interesting to note that the 2/20 and 1/40 load conditions were approximately an equal workload for the controllers.

•RPV Drone Control Data Retrieval System Studies

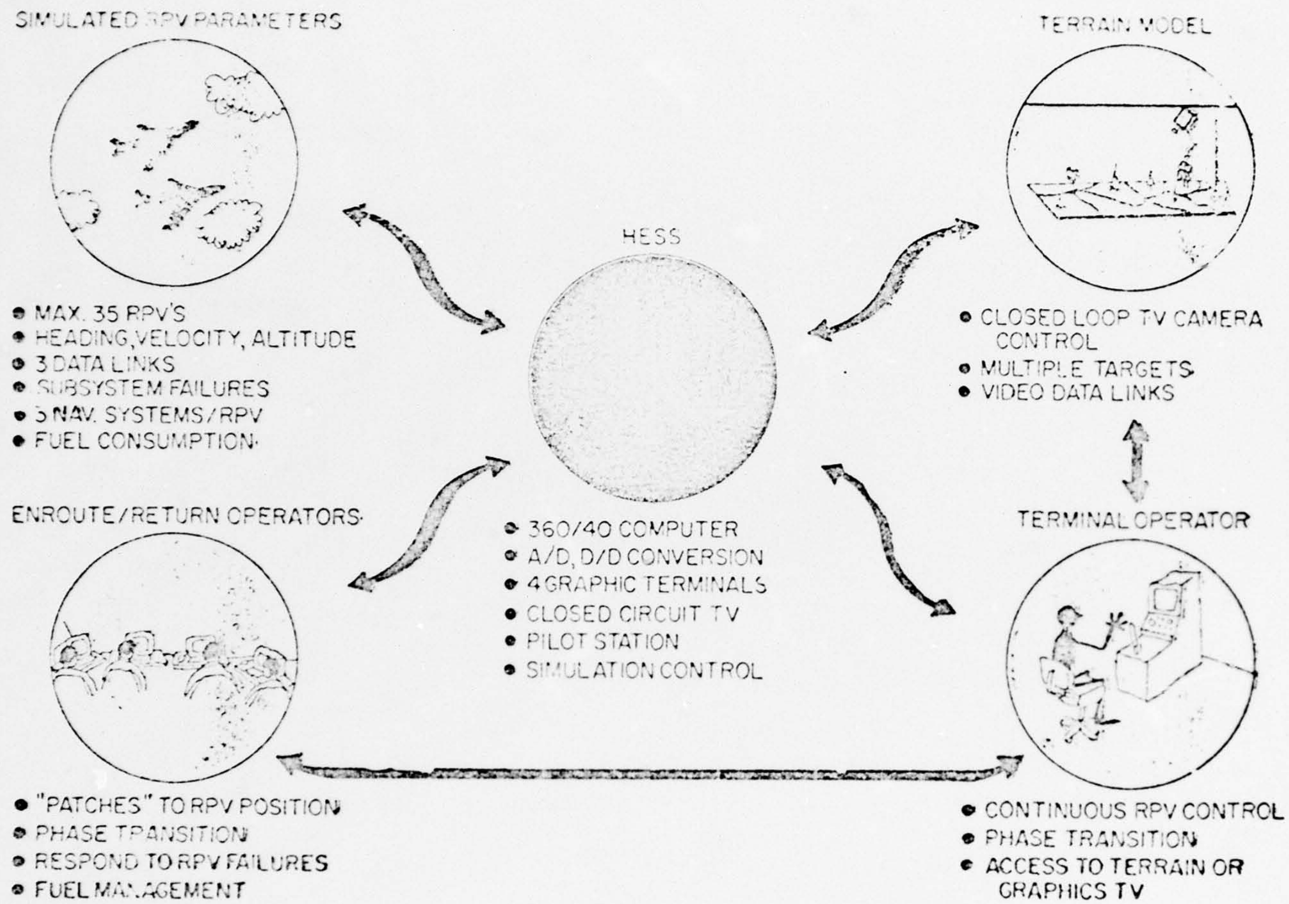
Our most advanced and highly evolved Man-Machine C^3 System Simulation is represented by our in-house attempts to answer key questions about operator/system control capabilities for a Remotely Piloted Vehicle (RPV) Drone Control and Data Retrieval System. Initial concerns of the RPV System Program Office (SPO) at Aeronautical Systems Division centered around issues dealing with the number of RPVs an operator or team of operators could control to perform strike, electronic warfare, and reconnaissance missions.

Fig 11 depicts the major elements of the multi-operator RPV simulation. It contains five major system component structures. At the center of the system is the Human Engineering Systems Simulator (HESS) which provides all of the major parametric control, A/D and D/A conversion, graphics display and terminal pilot station control. The other components include the major system parameters: up to 35 RPVs, reading velocity and altitude, 3 data links, subsystem failures, 3 navigational systems and fuel consumption; 4 midcourse operators who provided navigational patches, phase transition, fuel management and responded to RPV subsystem failures; a terrain model which had closed loop TV camera control multiple strike targets and different video data links; and finally the terminal strike operator who flew the birds to the target.

Results from a series of simulations in which system parameters were varied over the conditions of interest to the SPO indicated that operators could control up to four RPVs simultaneously and still meet the navigational cross track error limits and still hand off to a terminal operator at the designated way

FIG 11

MAJOR ELEMENTS OF THE MULTI-OPERATOR RPV SIMULATION



points. However, systems performance could be enhanced by providing automatic heading correction and a means for "smoothing" RPV position reports.

To, in part, verify the results achieved in the operator(s) in-the-loop real-time simulation and to establish verification of our Man-Machine Computer simulation methodology and language; a SAINT (Systems Analysis Integrated Network of Tasks) model and single-team simulation was developed for the RPV system.

Figs 12 and 13 shows the 23 RPV flight performance measures and the 15 operator control performance measures respectively that were measured in the real-time simulation. These same measures were used for SAINT model predictions. The sample model validation/verification results are displayed in Fig 14. Note that in all cases the real-time RPV simulation values for a given team of operators over multiple missions fall within the 95% confidence limits of the SAINT model predictions for the flight performance measures and the operator control measures.

By building a SAINT computer simulation model of such a complex multi parameter and multi-operator system we were able to uncover some defects in the initial real-time simulation. Fig 15 shows the interactive process between physical real-time simulation and computer modeling in pseudo time. Both the system experiments and the systems designer can use and benefit from such an interactive process.

4.0 Summary. In reviewing the fifteen year history of Man-Machine C^3 simulation in the Air Force we might conclude that from the sensed enemy tactical environment through the C^3 system to the Commander or Command authority that the problems fall into three major areas: real-time requirements of the sensed environment; the threat detection process and the threat assessment and command decision making.

Real-Time Requirement - The operational problem rests with the ability to optimize the cycle times between the sensed data

FIG 12

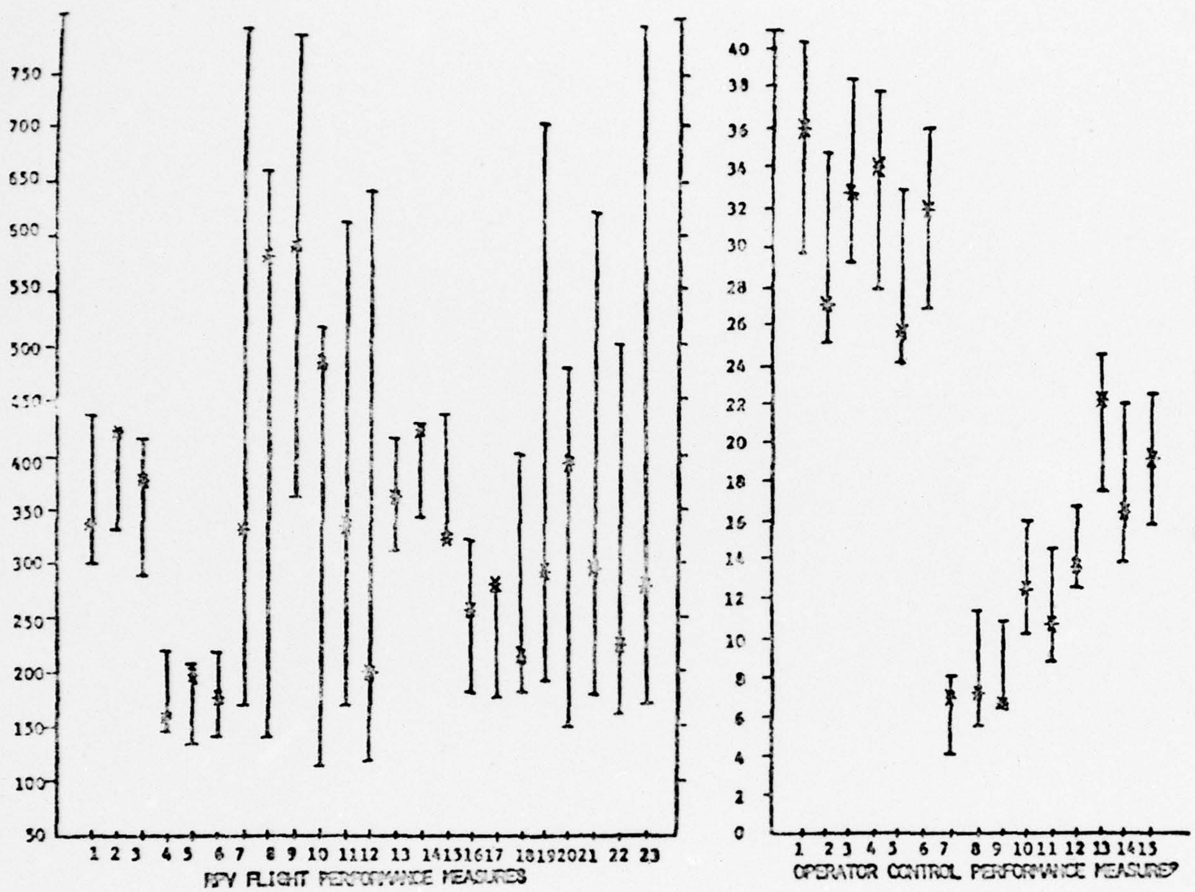
RPV FLIGHT PERFORMANCE MEASURES

1. AVERAGE CROSS TRACK ERROR DURING ENROUTE FOR S RPVs
2. AVERAGE CROSS TRACK ERROR DURING ENROUTE FOR E RPVs
3. AVERAGE CROSS TRACK ERROR DURING ENROUTE FOR L RPVs
4. AVERAGE GROUND SPEED ERROR DURING ENROUTE FOR S RPVs
5. AVERAGE GROUND SPEED ERROR DURING ENROUTE FOR E RPVs
6. AVERAGE GROUND SPEED ERROR DURING ENROUTE FOR L RPVs
7. AVERAGE CROSS TRACK ERROR AT H FOR S RPVs
8. AVERAGE CROSS TRACK ERROR AT H FOR E RPVs
9. AVERAGE CROSS TRACK ERROR AT H FOR L RPVs
10. AVERAGE GROUND SPEED ERROR AT H FOR S RPVs
11. AVERAGE GROUND SPEED ERROR AT H FOR E RPVs
12. AVERAGE GROUND SPEED ERROR AT H FOR L RPVs
13. AVERAGE CROSS TRACK ERROR DURING RETURN FOR S RPVs
14. AVERAGE CROSS TRACK ERROR DURING RETURN FOR E RPVs
15. AVERAGE CROSS TRACK ERROR DURING RETURN FOR L RPVs
16. AVERAGE GROUND SPEED ERROR DURING RETURN FOR S RPVs
17. AVERAGE GROUND SPEED ERROR DURING RETURN FOR E RPVs
18. AVERAGE GROUND SPEED ERROR DURING RETURN FOR L RPVs
19. AVERAGE CROSS TRACK ERROR FROM S TO H FOR S RPVs
20. AVERAGE GROUND SPEED ERROR FROM S TO H FOR S RPVs
21. AVERAGE CROSS TRACK ERROR AT S FOR S RPVs
22. AVERAGE GROUND SPEED ERROR AT S FOR S RPVs
23. AVERAGE CROSS TRACK ERROR FROM H AT PILOT CONTROL FOR S RPVs

OPERATOR CONTROL PERFORMANCE MEASURES

1. AVERAGE NUMBER OF PATCHES ATTEMPTED FOR S RPVs
2. AVERAGE NUMBER OF PATCHES ATTEMPTED FOR E RPVs
3. AVERAGE NUMBER OF PATCHES ATTEMPTED FOR L RPVs
4. AVERAGE NUMBER OF PATCHES COMPLETED FOR S RPVs
5. AVERAGE NUMBER OF PATCHES COMPLETED FOR E RPVs
6. AVERAGE NUMBER OF PATCHES COMPLETED FOR L RPVs
7. AVERAGE NUMBER OF VELOCITY CHANGES FOR S RPVs
8. AVERAGE NUMBER OF VELOCITY CHANGES FOR E RPVs
9. AVERAGE NUMBER OF VELOCITY CHANGES FOR L RPVs
10. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING ENROUTE FOR S RPVs
11. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING ENROUTE FOR E RPVs
12. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING ENROUTE FOR L RPVs
13. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING ENROUTE FOR S RPVs
14. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING RETURN FOR E RPVs
15. AVERAGE NUMBER OF PATCHES ATTEMPTED DURING RETURN FOR L RPVs

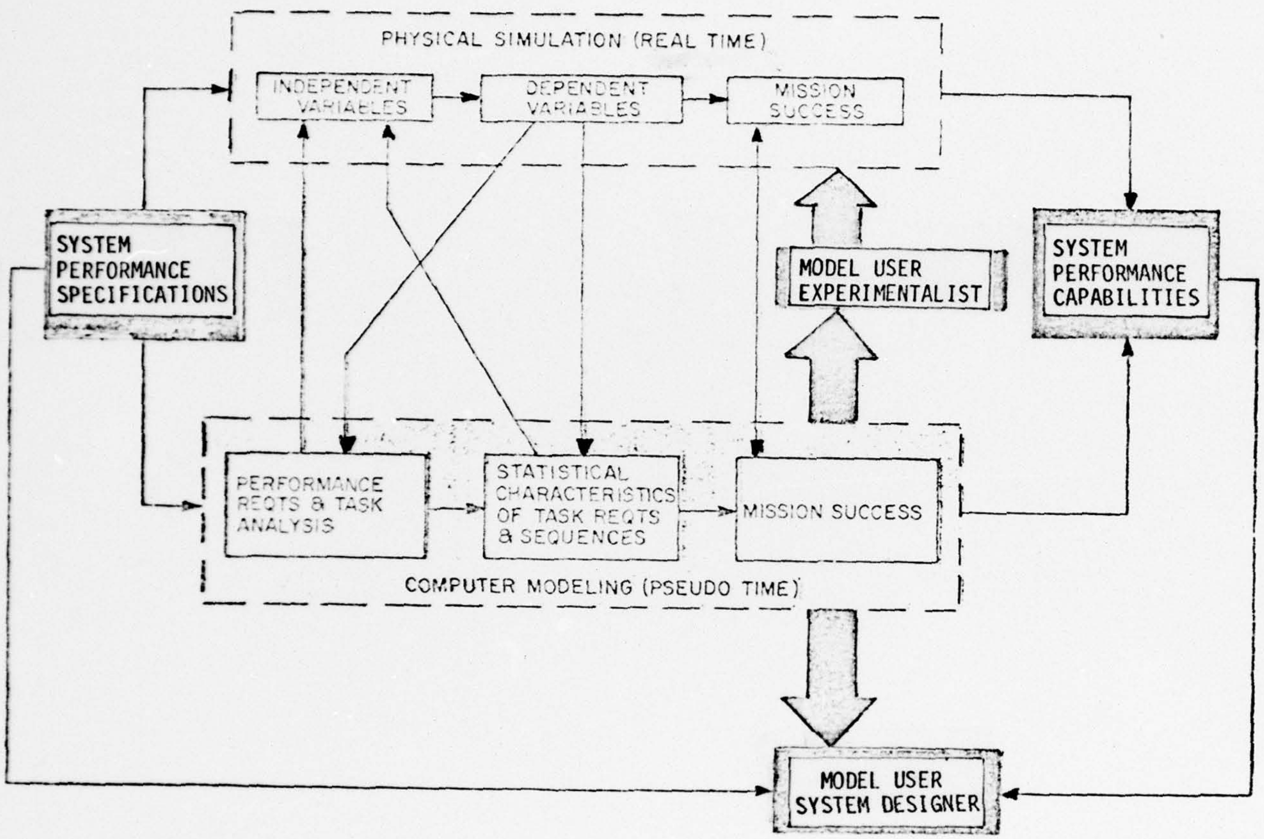
FIG 14



RPV FLIGHT PERFORMANCE MEASURES
OPERATOR CONTROL PERFORMANCE MEASURES

FIG 15

Man/Machine Systems Effectiveness Research



in the threat environment and the operator's/commander's ability to gain access to this information in an interactive fashion. The raw sensed data must be processed and transformed into usable information (e.g., track history for surveillance operators or interceptor availability/capability for weapons directors) Normally, it is assumed that the best design is one which minimizes access and cycle time. Evidence from simulations and operational environments suggest that cycle times less than 2-5 seconds for normal digitalized radar surveillance track loads are useless computer capacity. The expense in realizing these high computer speeds may not be warranted in terms of systems effectiveness criteria such as probability of detection P_D.

Threat Detection: The operational problem is that the probability of detection is less than 1.00, $P_d < 1.00$. The causative factors are to be found in hardware (e.g., radar sensing capability, computer capacity and speed, etc.) in human operators (e.g., perceptual discrimination between clutter and targets, ability to handle high target introduction rates, etc.) and software (e.g., radar filtering algorithms, radar correlational algorithms, etc.). Lack of data in these three areas and their interactions make it impossible to specify optimal system design parameters.

Threat Assessment and Command Decision Making: Today full advantage of computerized decision aids is not implemented in command and control systems although they are in effective use in the intelligence community. To assert that maximum decision effectiveness is not being achieved in advanced C^3 systems, implies that a quantitative rather than a qualitative standard of performance can be developed. Such a standard has been developed based on Bayes Theorem, implicit in which computer assistance techniques are available (e.g., the computer can perform certain computations, in this case, data aggregations to unburden the commander in minimizing the uncertainty of the data

available to him which bear on the decision alternatives).

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